

Standard for Rooftop Runoff Management

Definition

Modifications to conventional building design that retard runoff originating from roofs. The modifications include vegetated roof covers, roof gardens, vegetated building facades, and roof ponding areas.

Purpose Roofs are one of the most important sources of concentrated runoff from developed sites. If runoff is retarded at the source, the size of other BMPs throughout the site can generally be significantly reduced in size. Rooftop runoff management effectively increases the time of concentration of runoff derived from roofs, delaying runoff peaks and lowering runoff discharge rates.



Figure 1. Vegetated roof cover for a conventional flat roofed commercial building
(Courtesy of OPTIMA; Wilhelm Harzmann Modern Bausysteme)

Conditions Where Practice Applies

Managing rooftop runoff is of the greatest benefit in highly urbanized settings where space for other BMPs is limited. In addition to achieving specific stormwater runoff management objectives, rooftop runoff management is also aesthetically and socially beneficial. Rooftop runoff management measures are suitable for flat or gently sloping roofs. Furthermore, rooftop runoff management techniques can be retrofitted to most conventionally constructed buildings.

Vegetated Roof Covers:

Vegetated roof covers, also called green roofs and extensive roof gardens, involve blanketing roofs with a veneer of living vegetation. Vegetative roof covers are particularly effective when applied to extensive roofs, such as those that typify commercial and institutional buildings. The filtering effect of vegetated roof covers results in a roof discharge that is free of leaves and roof litter. Therefore, it is recommended where roof runoff will be directed to infiltration devices (see Standards for Infiltration Structures and Dry Well.)

Because of recent advances in synthetic drainage materials, vegetated covers now are feasible on most conventional flat roofs. An efficient drainage layer is placed between the growth media and the roof surface. This layer rapidly conveys water off of the roof surface and prevents water from “laying” on the roof. In fact, vegetated roof covers can be expected to protect roof materials and prolong their life.

Vegetated roof covers are an effective means of retarding runoff from roof surfaces. Initially during a rainfall event, nearly all precipitation striking the foliage is intercepted. As rain continues, water percolates into and begins to saturate the growth media and root zone of the cover. Not until the field capacity of the media is overcome will significant quantities of water begin to drain from the roof. For small rainfall events, little runoff will occur and most of the precipitation eventually will return to the atmosphere by evaporation and transpiration. For larger storms, vegetated roof covers can delay and attenuate the runoff peak significantly.

If materials are selected carefully to reduce the weight of the system, vegetated roof covers generally can be created on existing flat roofs without additional structural support. Drainage nets or sheet drains constructed from lightweight synthetic materials can be used as underlayments to carry away water and prevent ponding. Frequently, the total load of a fully vegetated and saturated roof cover system actually will be less than the design load computed for gravel ballast on conventional tar roofs.

Although vegetative roof covers are most effective during the growing season, they also are beneficial during the winter months if the vegetative matter from the dead or dormant plants is left in place and intact.

Roof Gardens:

Vegetated roof covers blanket an entire roof area and, although presenting an attractive vista, generally are not intended to accommodate routine traffic by people. Roof gardens, on the other hand, are landscaped environments, which may include planters and potted shrubs and trees. Roof gardens can be tailor-made natural areas, designed for outdoor recreation, and perched above congested city streets. Because of the special requirements for access, structural support, and drainage, roof gardens are found most frequently in new construction. The services of a professional engineer will be required to evaluate the architectural and engineering constraints associated with roof garden design.

Vegetated Building Facades:

Vegetated facades provide many of the same benefits as vegetated roof covers and roof gardens, including the interception of precipitation and the retardation of runoff. However, their effectiveness is limited to small rainfall events.

Vertical facades and walls of houses can be covered with the foliage of self-climbing plants that are rooted in the ground and reach heights in excess of 80 feet. Vines can be evergreen or prolific deciduous flowering plants. As for roof gardens, the designer must be judicious in selecting plant species that will prosper in the constructed environment. Planters and trellises can be installed so that vegetation can be placed strategically.

Roof Ponding:

Roof ponding is applicable where the increased load of impounded water on a roof will not increase the building costs significantly or require extensive reinforcement. Roof ponding generally is not viable for large-area commercial buildings where clear spans are required. Special consideration must be given to ensuring that the roof will remain watertight under a range of adverse weather conditions. Low-cost plastic membranes can be used to construct an impermeable lining for the containment area.

Flat roofs can be converted to ponding areas by restricting the flow to downspouts. Figure 1 shows a simple device that can be used to modify downspout inlets. The device features drain holes that will retard outflow as the water level rises and a weir ring that will allow free drainage once the design ponding level is attained. Even small ponding depths of 1 or 2 inches can attenuate stormwater-runoff peaks effectively for most storms.

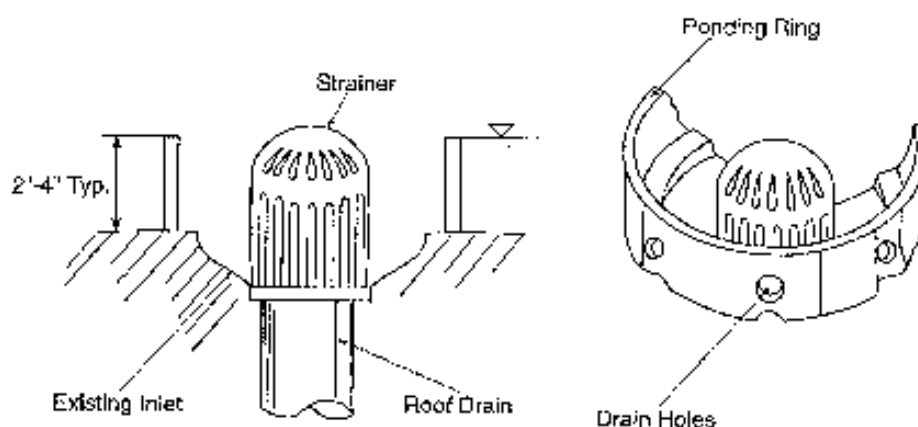


Figure 2. Modification of downspout inlet (Adapted from Tourbier, 1974).

Design Criteria

Rooftop measures are primarily runoff peak attenuation measures. The methods for evaluating the peak attenuation properties of these measures are based on approaches used for other runoff peak attenuation BMPs (see Extended Detention Basin).

Vegetated Roof Covers:

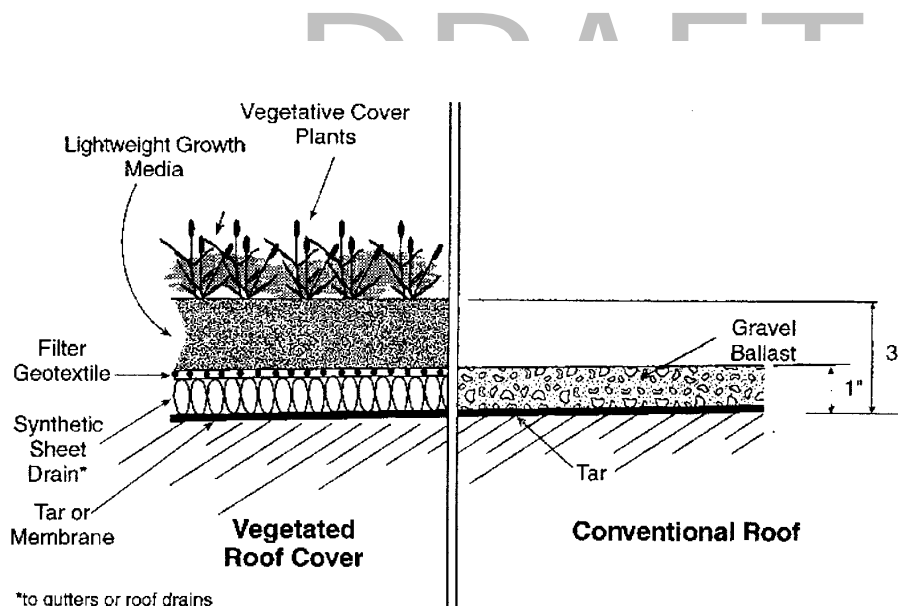
Runoff peak attenuation design storms larger than the 2-year return frequency event are generally not used in designing vegetated roof covers. However, vegetated roof covers will contribute to the attenuation of runoff peaks from larger storms, and should be taken into account when sizing related runoff peak attenuation BMPs at a site. The emphasis of the design should be promoting rapid roof drainage and minimizing the weight of the system. By using appropriate materials, the total weight of fully saturated vegetated roof covers can readily be maintained below 20 pounds per square foot (psf). At present, because most of the pioneering work has been done in Europe, many of the engineering design manuals are not yet available in English. Because of the many factors that may influence the design of

vegetated roof covers, it is advisable to obtain the services of installers that specialize in this area.

All vegetated roof covers share certain common design elements:

1. Impermeable lining.

In some instances, the impermeable lining can be the watertight tar surface, which is conventional for flat roof construction. However, where added protection is desired, a layer of plastic or rubber membrane can be installed immediately beneath the drainage net or sheet drain.



2. Drainage net or sheet drain.

The drainage net or sheet drain is a continuous layer that underlies the entire cover system. A variety of lightweight, high-performance drainage products will function well in this environment. The product selected should be capable of conveying the discharge associated with the runoff peak attenuation storm without ponding water on top of the roof cover. The drainage layer must have a good hydraulic connection to the roof gutters, drains, and downspouts.

To prevent the growth media from penetrating and clogging the drainage layer and to prevent roots from penetrating the roof surface, a geotextile should be installed immediately over the drainage net or sheet drain. Many vendors will bond the geotextile to the upper surface of the drainage material.

3. Lightweight growth media.

The depth of the growth media should be kept as small as the cover vegetation will allow. Typically, a depth of 3 to 4 inches will be sufficient. Low-density substrate

materials with good water-retention capacity should be specified. Examples are mixtures containing crushed pumice and terra cotta. Media that are appropriate for this application will retain 40 to 60 percent water by weight and have bulk dry densities of between 35 and 50 lb/cubic foot. Earth and topsoil are too heavy for most applications.

4. Adapted plants and grasses.

A limited number of plants can thrive in the roof environment where periodic rainfall alternates with periods that are hot and dry. Effective plant species must:

- Tolerate mildly acidic conditions and poor soil
- Prefer very-well-drained conditions and full sun
- Tolerate dry soil
- Be vigorous colonizers

Both annual and perennial plants can be used. Dozens of species have been successfully field tested. Among these, some species of sedum (*Sedum*) have been shown to be particularly well-adapted. Other candidates include hardy species of sedge (*Carex*), fescue (*Festuca*), feather grass (*Stipa*), and yarrow (*Achillea*).

Vegetative roof covers may include provisions for occasional watering during extended dry periods. Conventional lawn sprinklers work well.

Roof Gardens:

Roof gardens generally are designed to achieve specific architectural objectives. The load and hydraulic requirements for roof gardens will vary according to the intended use of the space. Intensive roof gardens typically include design elements such as planters filled with topsoil, decorative gravel or stone, and containers for trees and shrubs. Complete designs also may detain runoff ponding in the form of water gardens or storage in gravel beds. A wide range of hydrologic principles may be exploited to achieve stormwater management objectives, including runoff peak attenuation and runoff volume control.

Effective designs will ensure that all direct rainfall is cycled through one or more devices before being discharged to downspouts as runoff. For instance, rainfall collected on a raised tile patio can be directed to a media-filled planter where some water is retained in the root zone and some is detained and gradually discharged through an overflow to the downspout.

Vegetated Building Facades:

The key to developing an effective vegetated facade is selecting plants that are well-adapted to the conditions in which they must grow. For instance, depending on the location, plants may encounter shade or full sun. Plants that will provide thick foliage should be selected. Some plants with good climbing and foliage characteristics are ivy (*Hedera*), honeysuckle (*Loniciera*), wisteria (*Wisteria*), Virginia creeper (*Parthenocissus*), trumpet creeper

(*Campsis*), and hardy cultivars of clematis (e.g., *Cleimatis paniculata*). Some of these plants will require a trellis or lattice to firmly support the vines.

Roof Ponding Areas:

Roof ponding measures can be designed for rainfall events of all sizes. However, limitations on their use may be imposed by the structural loads associated with the impounded runoff. This is especially true if ponding areas must also accommodate runoff derived from adjacent roof surfaces. Devices, such as the one shown in Figure 2, are easily fabricated. However, some form of emergency overflow also is advisable. Emergency overflow can be as simple as a free overfall through a notch in the roof parapet wall. Many methods can be used for sealing roofs, including tar and mastics or plastic membranes. If membranes are used, their resistance to ultraviolet (UV) radiation, extremes of temperature, and puncture must be known. In most cases, covering the sealing material with a protective layer of gravel or geotextile is advisable.

Roof ponding areas are designed like any other above ground impoundment. To evaluate the performance of these measures, an appropriate runoff peak attenuation design storm must be selected and the hydraulic characteristics of the outlet device determined. Approaches for designing various rooftop runoff management measures are described below.

Vegetative Roof Covers:

Vegetative roof covers influence the runoff hydrograph in two ways:

1. Intercept rainfall during the early part of a storm
2. Limit the maximum release rate

Hydrologic properties are specific to the growth medium. If information is not provided by the supplier, prospective media should be laboratory tested to establish:

- Porosity
- Moisture content at field capacity
- Moisture content at the wilting point (nominally 0.33 bar)
- Saturated hydraulic conductivity

Rainfall retention properties are related to field capacity and wilting point. Appropriate media for this application should be capable of retaining water at the rate of 40 percent by weight, or greater. The media must be uniformly screened and blended to achieve its rainfall retention potential. During the early phases of a storm, the media and root systems of the cover will intercept and retain most of the rainfall, up to the retention capacity. For instance, a 3-inch cover with a 40 percent retention potential will effectively control the first 1.2 inches of rainfall. Although some water will percolate through the cover during this period, this quantity generally will be negligible compared to the direct runoff rate without the cover in place.

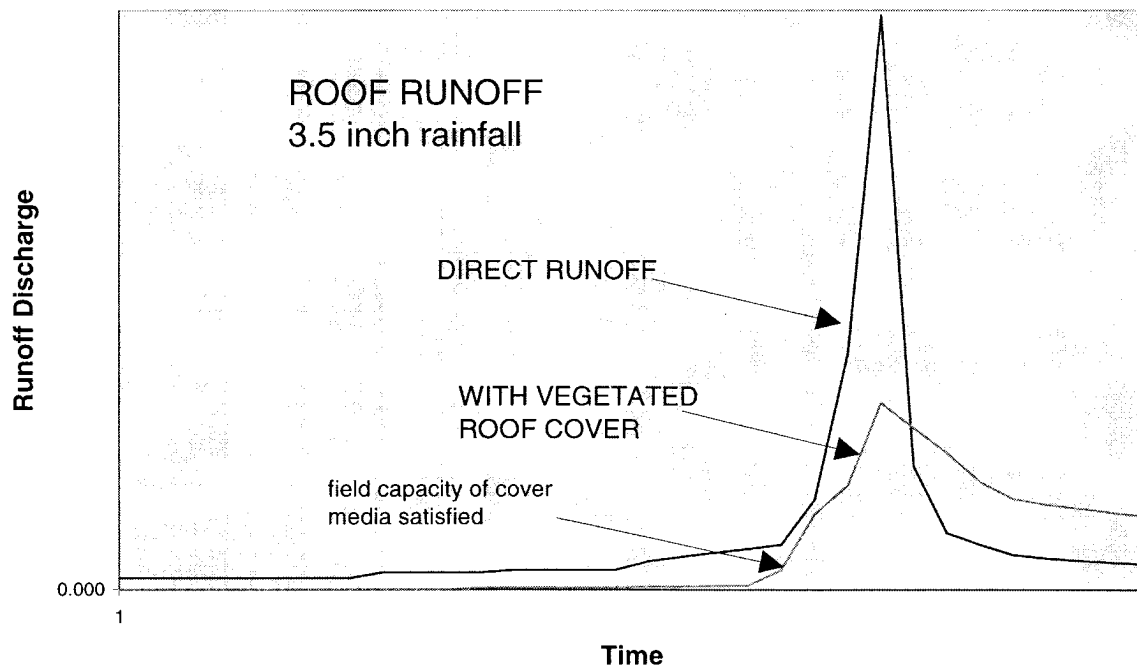


Figure 4. Influence of vegetated roof cover on runoff hydrograph

Once the field capacity of the cover is attained, water will drain freely through the media at a rate that is approximately equal to the saturated hydraulic conductivity for the media. Through the selection of the media, the maximum release rate from the roof can be controlled. The media is a mechanism for “buffering” or attenuating the peak runoff rates from roofed areas. The attenuation can be important even for large storms. By using specific information about the hydraulic properties of the cover media, the effect of the roof cover system on the runoff hydrograph can be approximated with numerical modeling techniques. As appropriate, the predicted hydrographs can be added into sitewide runoff models to evaluate the effect of the vegetative roof covers on site runoff. The hydraulic analysis of roof covers will require the services of a professional engineer who is experienced with drainage design.

Drainage nets or sheet drains with transmissivities of 15 gallons per minute per foot, or larger, are recommended. When evaluating a drainage layer design, the roof topography should be evaluated to establish where the longest travel distances to a roof gutter, drain, or downspout occur. If flow converges near drains and gutters, the design unit-flow rate should be increased accordingly. The drainage layer should be able to convey the design unit flow rate at the roof grade without water ponding on top of the cover media. For larger storms, direct roof runoff is permitted to occur. The design flow rates should be based on the largest runoff peak attenuation design storm considered in the design of the vegetated roof cover.

The net weight of the fully vegetated roof cover should be compared against the design loads for the roof. Preliminary designs commonly are too light to satisfy the ballast requirements for flat tar roofs. As required, the weight of the cover system can be increased by deepening the media. In Pennsylvania, the maximum roof design loads

must incorporate expected snow accumulation. The design snow load should be added to the weight of the roof system.

Roof Ponding:

The analysis of roof ponding systems is very similar to the design of extended detention basins and other runoff peak attenuation facilities. The necessary inputs are:

1. Input hydrograph
2. Depth-storage function
3. Depth-discharge function

Because the roof is impermeable, the runoff hydrograph is simply the rainfall distribution for the design storm multiplied by the area of the roof. The depth to storage relationship can be computed from the topography of the roof. For perfectly flat roofs, the storage volume of a ponding level is equal to the roof area times the ponding level. The depth-discharge relationship will be unique to the outlet device used. For simple ponding rings, the discharge rate will approximately equal:

$$O = C \times 3.141 \times D \times (d - H)^{3/2}$$

where:

- O = outflow rate
- D = diameter of the ring
- d = depth of ponding
- H = height of the ring
- C = discharge coefficient

Considerations

Rooftop runoff management measures generally are more effective in controlling storms with magnitudes typical of 2-year return frequency storms or smaller. However, because storms of this size constitute the majority of rainfall events, rooftop runoff measures can be important in planning for comprehensive stormwater management. The measures are particularly useful when linked to groundwater recharge BMPs such as infiltration trenches, dry wells, and permeable pavements. By retaining rainfall for evaporation or plant transpiration, some rooftop runoff management measures, such as vegetated roof covers, can also achieve significant reductions in total annual runoff.

For reasons of broad applicability, cost, and effectiveness, vegetative roof covers offer particular advantages for urban design. In addition to managing stormwater, many ancillary benefits exist:

- Reduces energy consumption for heating and cooling
- Conserves space
- Reduces wear on roofs caused by UV damage, wind, and extremes of temperature

Roofs that are sheltered by vegetative covers have long life expectancies compared to conventional tar roofs that are exposed to UV and extremes of temperature.

Vegetative roof covers can reduce bare roof temperatures in summer by as much as 40 percent. Because of the insulating properties of the covers, significant saving in both heating and cooling energy are achievable. The savings in energy costs and the extended life of the roof will frequently offset the additional capital costs of vegetated roof covers. Vegetative roof covers are a proven technology in central Europe where urban population density is higher than in most American cities. Several European cities, in an effort to reduce the overloading of sewer systems, provide incentives for homeowners to install vegetated roof covers or roof gardens. Some of the cities are Stuttgart, West Berlin, Cologne, Dusseldorf, and Hamburg.

Roof gardens, vegetated roof covers, and vegetated facades add aesthetic value to residential and commercial property. In addition to the attractive textures and colors of the foliage, these natural urban islands attract song birds, bees, and butterflies. Although the methods should not be used as water quality measures, they will benefit water quality by reducing the acidity of runoff and trapping airborne particulates.

Operation and Maintenance

All rooftop runoff management measures must be inspected and maintained periodically. Furthermore, the vegetative measures require the same normal care and maintenance that a planted area does. The maintenance includes attending to plant nutritional needs, irrigating as required during dry periods, and occasionally weeding. The cost of maintenance can be significantly reduced by judiciously selecting hardy plants that will outcompete weeds. In general, fertilizers must be applied periodically. Fertilizing usually is not a problem on flat or gently sloping roofs where access is unimpeded and fertilizers can be uniformly broadcast. Properly designed vegetated roof covers should not be damaged by treading on the cover system. Maintenance contracts for the routine care of the vegetative cover frequently can be negotiated with the installer.

When retrofitting existing roofs, preserve easy access to gutters, drains, spouts, and other components of the roof drainage system. It is good practice to thoroughly inspect the roof drainage system quarterly. Foreign matter, including leaves and litter, should be removed.

NOTE: Additional guidance can be obtained from the Standards for Soil Erosion and Sediment Control in New Jersey.

NOTE: This Standard was adapted from: Pennsylvania Handbook of Best Management Practices for Developing Areas, 1998. Pennsylvania Association of Conservation Districts, Pennsylvania Department of Environmental Protection, Harrisburg, PA.

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